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UTILIZATION OF WIND POWER

WITH WARD-LEONARD TYPE CIRCUIT

IN INVERTED OPERATION

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or an asynchronous induction machine suitable for transforming
and feeding the energy from the wind into a three-phase
conventional electric power network.

I. Introduction and Description of Circuit

On 7 December 1948, at the Turin Session of the Italian
Electrotechnical Society, the author held a conference on the
subject: "Direct current generators for utilizing the energy
of the wind"*. During the discussion which followed the
exhibition, engineer Dario Morbiducci with Tecnomasio Italiano
Brown Boveri proposed, with felicitous intuition, to study
if it was possible to utilize the energy of the wind and
feed this same energy into a three-phase conventional network
by using an electrical circuit comprising the same machines
used in a Ward-Leonard system, but the normal flow of energy
would be from the dc ring to the three-phase network rather
than from the three-phase network to the dc ring.

It is now possible to give an answer to this same engineer,
to whom we also give our cordial thanks for the useful suggestion.

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* A. Carrer: Direct current generators for utilizing the
  energy of the wind. "L'Elettrotecnica", August 1949,
  XXXVI, 8, page 376.

** Numbers in margin indicate pagination in original foreign text.
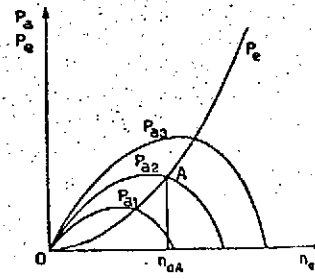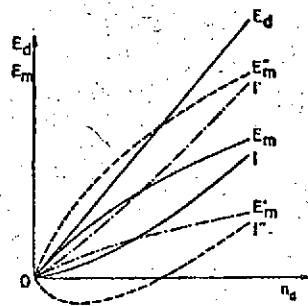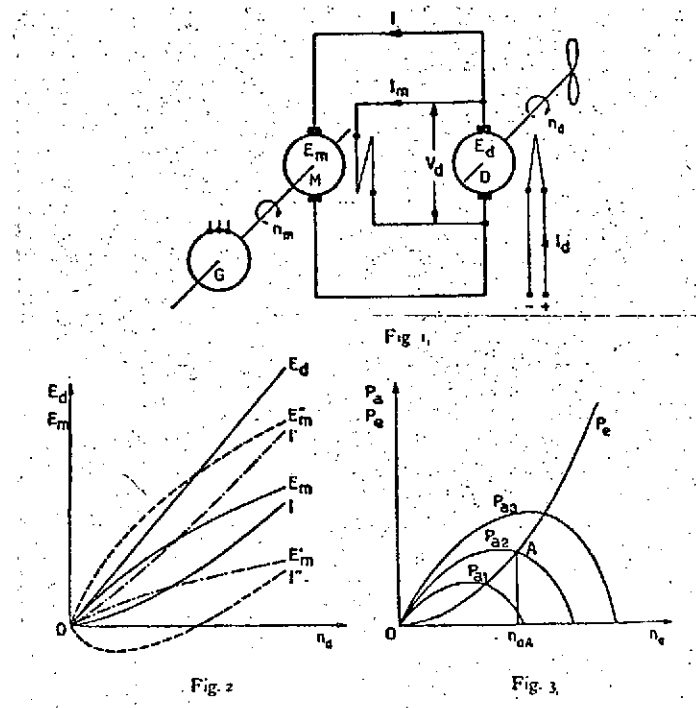
Fig 1.

Fig. 2

Fig. 3.

Figure 1. Inverted Ward-Leonard system for utilizing energy obtained from the wind and feeding it into a polyphase electric circuit.

Figure 2. EMF and current characteristics for the machines constituting the group under consideration in Figure 1 for various conditions.

Figure 3. Power characteristics for the wind engine and the generator it drives.

It is believed that the basic circuit of the group can be realized as indicated in Figure 1. Here the generator D is driven by the wind engine and is excited with constant ampere turns by means of current I_d supplied by an independent electrical energy source. The same generator is inserted in a

ring which includes the dc motor M which is keyed on the same shaft that carries the polyphase synchronous or an asynchronous induction generator G connected to the conventional electric power network. The excitation for motor M is obtained from the current I_m produced by the voltage V_d generated by generator D.

If for a moment we disregard secondary phenomena, it can be seen that generator D produces an emf E_d as a function of the velocity n_d at which it is driven by the aero-engine. E_d can be represented as a straight-line function of this velocity n_d as indicated in Figure 2 because its excitation is presumably constant. Correspondingly motor M produces an emf E_m whose variation as a function of the velocity n_d of the wind engine can be represented by a curve having the shape of a magnetic characteristic since the speed of the motor M is constant and the excitation current I_m is proportional to the voltage V_d or approximately proportional to the emf E_d, which in turn is proportional to the speed n_d. If the /384 resistance R_m of the circuit I_m flows through is of a suitable value, the variation in E_m may be of the type indicated in Figure 2. It is then evident that the variation in the current I as a function of n_d will be analogous to the variation in the difference E_d-E_m between the emf's produced by the generator and by the motor since the resistance of the circuit the current I flows through is supposed to be constant. The current I will then vary as shown in Figure 2.

It is evident that if the value of the resistance R_m were greater, the variation of E_m and I would assume the shape shown in Figure 2 with dots and dashes (curves E_m', I'), while if the value were smaller, the same variation would assume the other shape shown by the dashed lines (curves E_m'', I''). It is also evident that the variation in the current I does not depend on the value chosen for the resistance R_m alone,

but also on the saturation conditions for the magnetic circuit of motor M, and by varying these one can obtain a more or less straight characteristic. For instance, the current I can be made to be approximately proportional to $n_d{}^2$ over a certain range of variation in the velocity n_d. The power produced by the generator D will then be proportional to the product $E_d I$ and thus proportional to $n_d{}^3$, since the emf E_d is already proportional to n_d.

The energy of the wind engine can thus be utilized in a rational manner.

Finally it is easy to confirm that it is possible to arrange the system consisting of the wind engine and the electrical machines so as to give stable operation without requiring special equipment. In fact, we will consider Figure 3 where some curves for the power P_a of a wind engine are shown qualitatively. Each curve shows the power generated as a function of the speed n_d of the wind engine for a fixed wind velocity. The three curves P_{a1}, P_{a2}, P_{a3} are, in order, for three different wind velocities with increasing values. If the same curves are intersected by the curve P_e, which represents the electrical power consumed by generator D] as a function of the speed n_d as is also shown on Figure 3, it is evident that the operation of the system is stable since corresponding to each wind speed, for instance, the one corresponding to the wind engine curve P_{a2}, the operation will take place corresponding to point A. In fact, if the speed of the system were to be greater than n_{dA}, the electric power would prevail over that of the wind engine and the velocity n_d would decrease, while if it were lower, the opposite would happen.
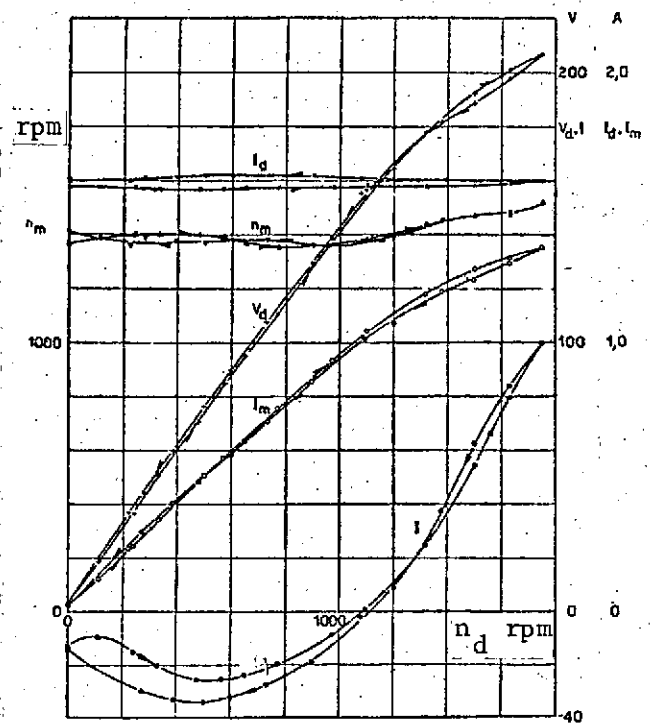
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Figure 4. Experimentally measured characteristics.
Motor M has too much excitation.

In principle, one can thus conclude that it is possible to operate the machines which will make up the group considered in Figure 1, and they may be calculated so that a large amount of the energy which can be captured with the wind engine will be utilized.

Secondary phenomena have been disregarded in this discussion in order to simplify the reasoning, but it is clear that for the type of machines considered there are no difficulties in calculating and especially in evaluating the effects of the ohmic losses and the phenomena resulting from
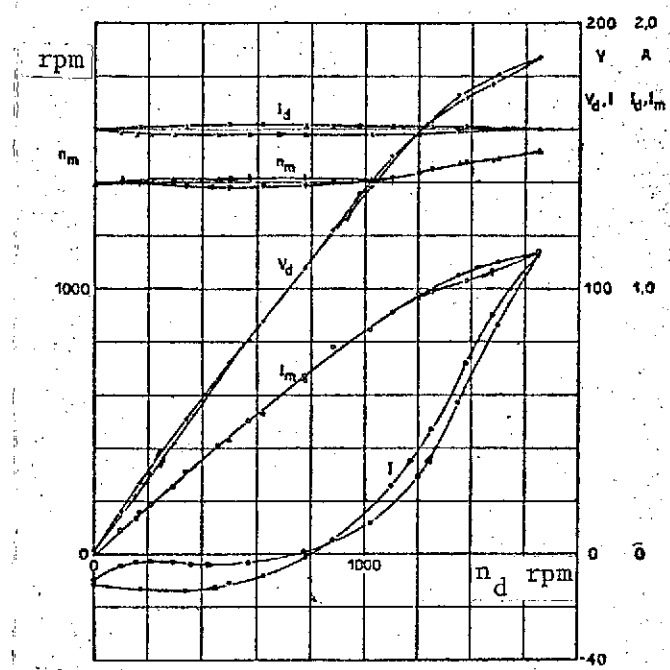
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Figure 5. Experimentally measured characteristics.
Motor M still has too much excitation.

the induced reactions and the heating. For this purpose it
is perhaps useful to notice how convenient it is to operate
the generator D in a condition of relatively high magnetic
saturation in order to prevent the voltage V_d from increasing
proportionately with n_d beyond a certain limit because of the
induced reaction phenomena when the current I increases.

2. Experimental Measurements

Experimental measurements were carried out in order to confirm the theoretical predictions, and the characteristics were derived with machines arranged according to the diagram indicated in Figure 1. The characteristics plotted in Figures 3, 4 and 5 were derived. Here the quantities plotted correspond to those shown in Figure 1.

The measurements were made for three different values of the resistance R_m. The values were such that the curve which represents the current I as a function of the speed of rotation n_d of the generator D expressed in rpm had different variations. The speed of the motor M also expressed in rpm is indicated on the figure by n_m.

The characteristics were derived by varying the speed /385 n_d steadily first increasing the values from zero and then decreasing them after having reached a maximum value. The result was that for low values of the speed, the current I assumes smaller values when the speed is decreasing because at the same velocity the emf E_m is larger when the speed n_d decreases than when this same speed increases because of the hysteresis in the magnetic circuit of the motor M. On the other hand, for high values of the speed the behavior of the current I is opposite. This is because the temperature of the excitation windings which this same current I_m passes through rises fast and the winding is therefore warmer when the speed decreases, and the current I_m and thus the emf E_m are accordingly smaller. The current I therefore becomes larger for the same n_d.

The three characteristics which represent the mean values of the current I derived from the curves shown in Figures 3, 4 and 5 are plotted in Figure 6 as functions of the speed n_d of the generator.
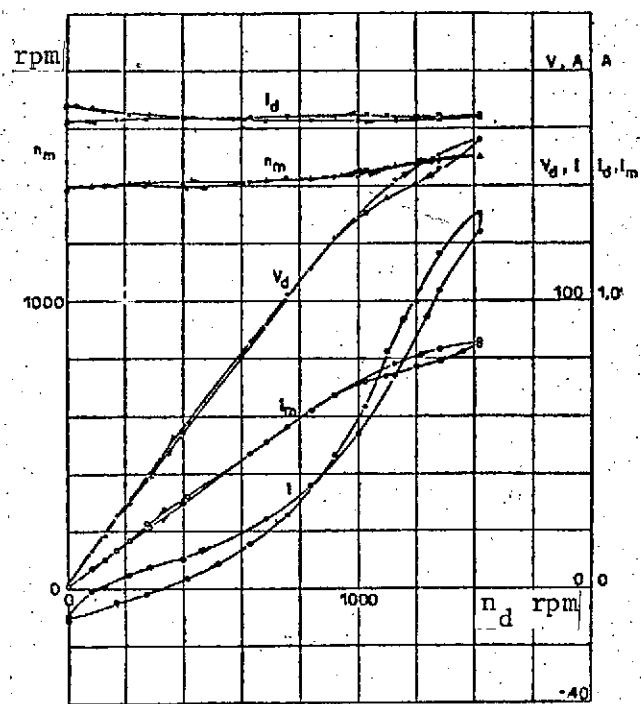
Figure 6. Experimentally measured characteristics.
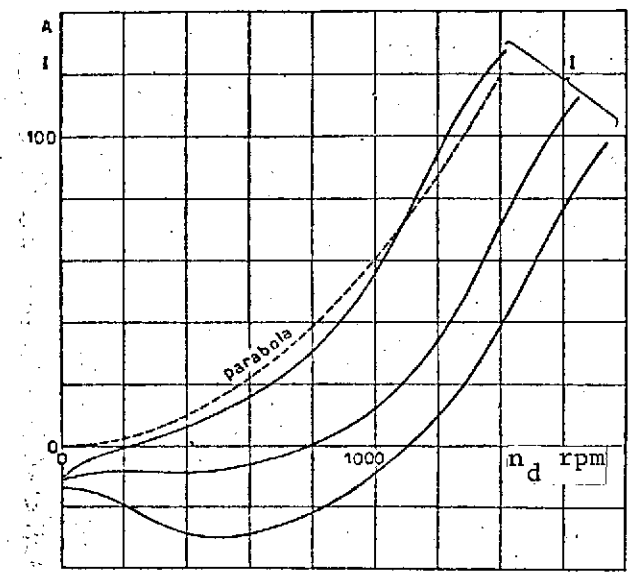The motor M is properly excited.

Figure 7. Comparison of the current characteristics.

From the curves it can be seen that all the current characteristics I converge approximately towards the same negative current value when the speed of the generator D goes to zero. This is because when the generator D has stopped, a negative current I produced by the emf which the motor M generates with its residual magnetism circulates in the circuit of the two DC machines.

One should also note that for the higher generator speed n_d values the values of V_d and thus the values of I_m do not follow these straight lines which can be observed for the lower speeds because of phenomena caused by the ohmic losses connected with, among other things, the temperature variations in the windings and phenomena caused by the inductive reaction in generator D. On the same figure has also been plotted with a dotted line a parabola having the ordinate proportional to the square of the speed n_d of the generator D, and it can be seen that this curve is relatively close to the highest current characteristic I.

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15. Supplementary Notes

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16. Abstract

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